

Matter Radiation Interactions in Extremes (MaRIE)

Los Alamos National Laboratory is developing a future signature experimental facility concept that would provide transformational materials solutions for today's and tomorrow's national security needs. Named MaRIE (Matter Radiation Interactions in Extremes), it would provide an integrated approach to solving national grand challenges of energy security (closing the 10 TW gap between the energy we have and the energy we need), nuclear security (transforming the nuclear weapons enterprise by defining process-aware materials performance), and national security (ubiquitously detecting global threats). It would do this by achieving transformational materials performance through predictive multi-scale understanding of materials with an emphasis on radiation-matter interactions.

The current baseline approach involves plasma physics in two primary ways. First, the issues of materials and the plasma facing components have been identified as the highest priority, top-tier problems facing fusion energy. MaRIE's Fission and Fusion Materials Facility will create extreme radiation fluxes with unique in-situ diagnostics and irradiation environments comparable to best planned facilities. This facility would be a component in addressing the grand challenge of engineering the first wall of a fusion reactor.

The second connection of MaRIE to plasma physics is through the planned Multi-Probe Diagnostic Hall, which is intended to provide unprecedented probes of matter, using x-ray scattering capability at high energy and high-repetition frequency with simultaneous proton imaging. The current baseline plan that meets the scientific requirements would be a 50-keV photon energy x-ray free-electron-laser (XFEL). In addition to the primary mission of learning to control multi-scale materials properties, the diagnostics and probes of this facility can be used to study cold plasmas or warm dense matter. While such a facility is a decade in the future, its development is driving Los Alamos participation in near-present cutting-edge facilities such as the Linac Coherent Light Source at Stanford University and FLASH and European XFEL at DESY in Germany.

Contact: Cris Barnes, P-DO

Physics Deputy Division Leader **Cris W. Barnes** (PhD Princeton) is a former P-24 group leader and program manager for Science Campaigns 4 and 10. He helped staff the federal Interagency Task Force on High-energy-density Physics while on change-of-station in Washington.

Kirk Flippo (PhD, nuclear engineering from the University of Michigan, 2003, studying under Prof. Don Umstadter group at CUOS). In 2004 he joined Los Alamos as a postdoctoral researcher in P-24. He is the principal investigator on experiments which produced the world record for ion acceleration and the highest efficiency on an experiment using novel hollow gold cone targets for fast ignition research.

Manuel Hegelich is team leader for Shortpulse Experiments and Lasers in the P-24 Group. Having worked in optical technology and relativistic ultrahigh intensity laser physics, he received his PhD from the Ludwig-Maximilian-University of Munich in 2002 and after a postdoctoral position became a staff member at Los Alamos in 2005.

John Kline graduated with his PhD from West Virginia University in the spring of 2002 and became a postdoctoral researcher at LANL in the plasma physics group, P-24. In 2005 he was converted to a technical staff member and in 2006 became a project leader for the Inertial Confinement Fusion program.

David Montgomery is the Director of the Trident Laser Facility, and is the Team Leader for Laser-Matter Interactions in P-24. He is an internationally-recognized expert in laser-plasma instability physics and is a fellow of the American Physical Society.

Glen A. Wurden is the team leader for magnetic fusion experiments at Los Alamos and LANL's Fusion Energy Sciences program manager. He is an experimental plasma physicist interested in creating fusion energy by both conventional and alternative techniques, including using high-energy-density laboratory plasmas.

P-24 Deputy Group Leader **Jonathan Workman** graduated from the University of Michigan's Center for Ultrafast Optical Science. His interests in laser-produced x-rays have led to research in high energy density physics as related to ICF and science-based stockpile stewardship programs.

Tom Intrator is a Technical Staff Member at Los Alamos National Laboratory, P-24 Plasma Physics group. He is the principal investigator for FRX-L, the LANL portion of Magnetized Target Fusion experiments. He also leads the Reconnection Scaling Experiment, and the LANL Applied Science Internship Program for student interns.

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High-energy-density Plasma Physics

C. Barnes¹, K Flippo², M. Hegelich², J. Kline², D. Montgomery², G. Wurden², J. Workman², and T. Intrator²

High-energy-density plasma physics is a core capability at Los Alamos National Laboratory (LANL) and is important to supporting mission-relevant research in energy security, national security, and threat detection. The experimental physical science capability in the high-energy-density regime is largely concentrated in Physics Division and its Plasma Physics (P-24) group after a recent reorganization intended to concentrate and focus Los Alamos experimental research efforts.

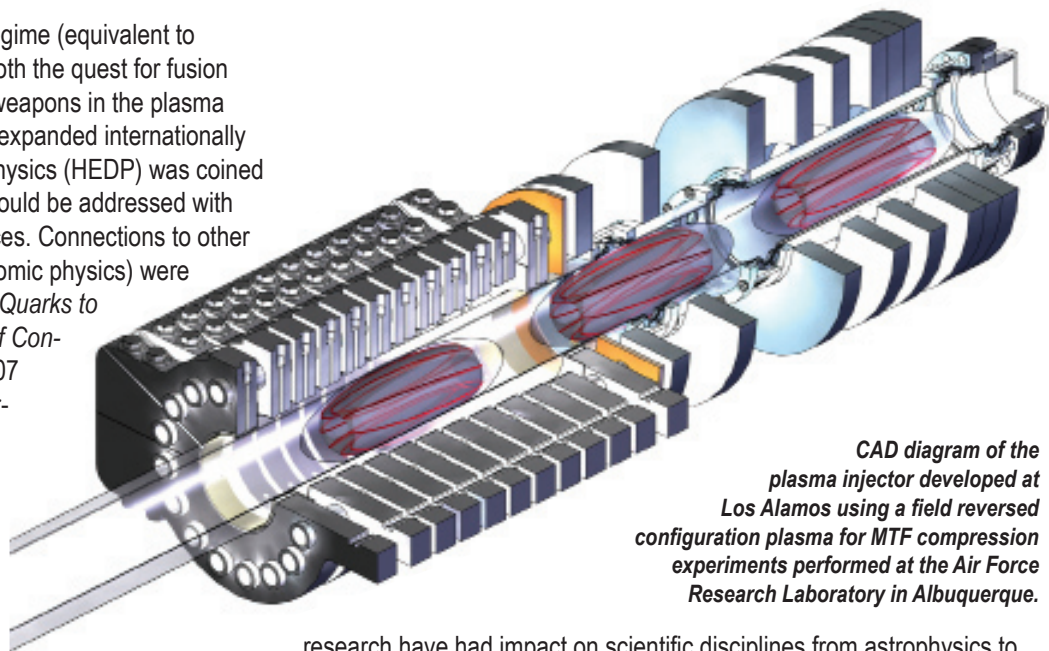
Plasma physics in the high-energy-density regime (equivalent to pressures over 1 megabar) has at its roots both the quest for fusion energy and the need to understand nuclear weapons in the plasma state. As experimental capabilities grew and expanded internationally in the 1990s, the term high-energy-density physics (HEDP) was coined to cover many topical areas of science that could be addressed with high-power lasers and/or pulsed-power devices. Connections to other disciplines (nuclear physics, astrophysics, atomic physics) were found as the overall HEDP field grew. (From *Quarks to Cosmos*, NRC Report 2003; *The X-Games of Contemporary Physics*, NRC Report 2003) In 2007 the federal government recognized the importance of stewardship of the original plasma physics part of the field, (*Interagency Task Force Report on High Energy Density Physics*, 2007) and a joint program (between DOE Office of Fusion Energy Science and the National Nuclear Security Administration) in HEDLP was formed.



Six current important areas of experimental research in HEDLP at Los Alamos are described below.

Laboratory plasma physics for stockpile stewardship

Research on high-energy-density laboratory plasmas at Los Alamos historically largely has been supported by the inertial confinement fusion program and for support of science-based stockpile stewardship. Los Alamos has excelled in the scientific studies of radiation transport and radiation hydrodynamics, of hydrodynamic instability and mix, and of the properties of warm dense matter. We have featured efforts to do the best physics on the best facilities, being involved in experiments at Z, OMEGA, OMEGA-EP, National Ignition Facility (NIF), Trident, and on small-scale lasers. Results from these experiments are both published in high-impact scientific journals and used for validation of design codes in the nuclear weapons program. Discoveries from this type of



CAD diagram of the plasma injector developed at Los Alamos using a field reversed configuration plasma for MTF compression experiments performed at the Air Force Research Laboratory in Albuquerque.

research have had impact on scientific disciplines from astrophysics to turbulence to fusion energy.

Contact: Jonathan Workman, deputy group leader, P-24

Magnetized target fusion

Since the early 1950s, Los Alamos has conducted research into ways to achieve controlled thermonuclear fusion to eventually create a new energy source for the benefit of mankind. In the last decade, LANL has largely focused on collaborating with other experimenters around the world to build and diagnose the most advanced experimental fusion machines. Meanwhile, several scientists at LANL are developing a new fusion concept to explore and establish a reduced cost path and timeline towards a more attractive practical fusion energy system. This concept, generically called "magnetized target fusion" (MTF), attempts to combine and leverage the best features of the more established approaches of magnetic fusion energy (MFE) and inertial fusion energy (IFE). It uses an inertial approach to compress and heat the plasma (like IFE), but uses a magnetic field to confine the plasma energy (like MFE). However, unlike conventional MFE, it is not limited to typical terrestrial magnetic field strengths, and unlike IFE, it can use slower, and therefore, cheaper pulse energy drivers. The research program at LANL involves efforts (1) to demonstrate a suitable plasma injector, called the

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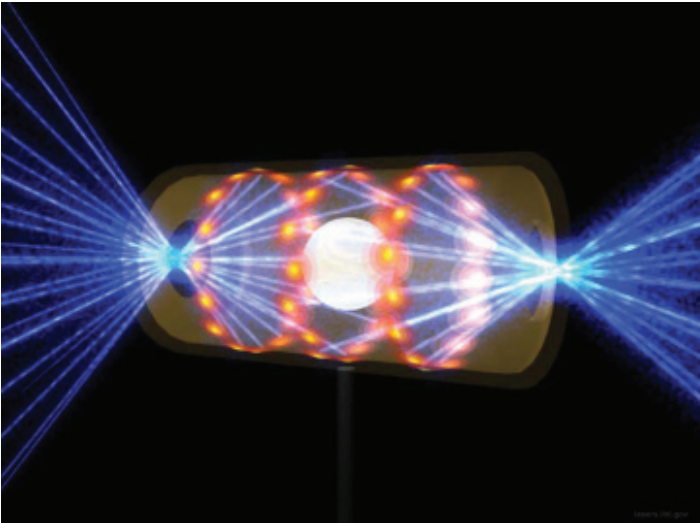
“FRX-L,” where FRX refers to “field-reversed experiment,” and the “L” refers to “liner” or metallic can that surrounds the plasma, (2) to develop the “can crusher” at the Air Force Research Laboratory (AFRL) in Albuquerque, New Mexico and mate it to the plasma injector, and (3) to predict and model the plasma implosions using sophisticated computer codes with data from fast-plasma diagnostic tools. MTF experiments can also lead to unique high-temperature, highly magnetized plasma conditions of considerable basic research interest.

Contact: Glen Wurden, program manager, P-24
Tom Intrator, FRX-L principal investigator, P-24

The National Ignition Campaign

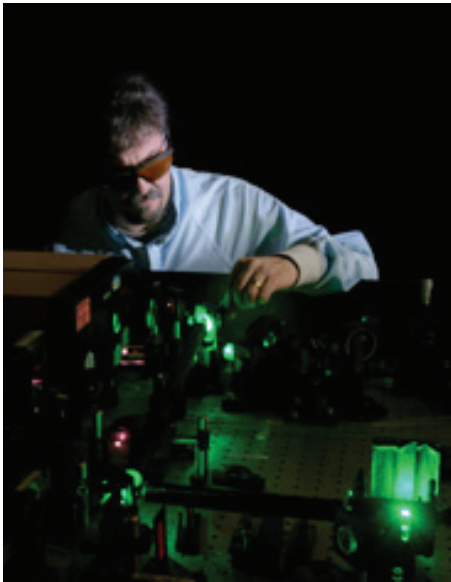
Los Alamos National Laboratory is a key participant in the National Ignition Campaign (NIC) and has been since its inception in the summer of 2005. This high-profile program focuses the efforts of the national Inertial Confinement Fusion (ICF) program on the goal of demonstrating a credible attempt at indirect drive ignition (x-ray) on the NIF by 2010 and achieving laser driven thermonuclear ignition by 2012. Los Alamos, as the only other design laboratory beyond Lawrence Livermore National Laboratory (LLNL) with the broad skills, knowledge and abilities in all of the topics of indirect-drive ignition, contributes to several important physics areas of the ignition program. Los Alamos has led efforts on predictive capability in laser-plasma instabilities, on measurement and control of the x-ray symmetry used to drive the implosion, and on capsule ablator material dynamics. Los Alamos staff are world leaders in developing and implementing diagnostic capabilities for ICF, such as fusion products (neutron imaging, burn history, radiochemical diagnosis), and fast x-ray imaging. Our efforts in the NIC support our long-term interest of realizing the scientific grand challenge of ignition in the laboratory. Moreover, the high-precision implosions possible on NIF enable advanced ignition applications and studies of burn physics. In addition, the success of ICF in the laboratory opens the gateway to inertial fusion energy, a potential path towards a clean, carbon-neutral energy source.

Contact: John Kline, project leader, P-24



An artist's rendering of an inertial confinement fusion indirect drive target showing the incident laser beams, the hohlraum case, and the fusion capsule. (Photo courtesy of Lawrence Livermore National Security, LLC, Lawrence Livermore National Laboratory, and the Department of Energy under whose auspices this work was performed.)

The flexibility and unique characteristics of the Trident laser make it an ideal facility for performing many experiments in high-energy-density physics.
<http://trident.lanl.gov/>



Trident Laser Laboratory as an intermediate-scale national user facility

The Trident Laser Facility at Los Alamos National Laboratory is an extremely versatile Nd:glass laser system dedicated to high-energy-density physics research and fundamental laser-matter interactions. Trident's unique laser capabilities and many diagnostics provide an ideal platform for many experiments. The laser system consists of three high energy beams which can be delivered into two (and soon to be three) nearly-independent target experimental areas. The target areas are equipped with an extensive suite of diagnostics for research in ultra-intense laser matter interactions, dynamic material properties, and laser-plasma instabilities.

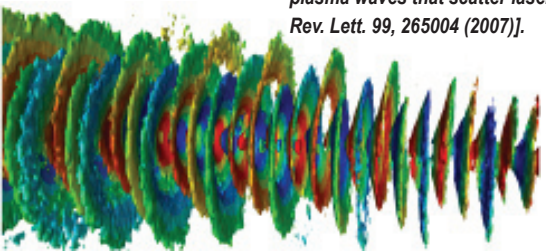
Several important discoveries and first observations have been made at Trident, including laser-accelerated MeV mono-energetic ions, nonlinear kinetic plasma waves, transition between kinetic and fluid nonlinear behavior, as well as other fundamental laser-matter interaction processes. Trident's unique long-pulse capabilities have enabled state-of-the-art innovations in laser-launched flyer-plates, and other unique loading techniques for material dynamics research, including studies of incipient spall and effects of microstructure on shocks.

The Trident Laser Facility is now being operated in support of a national user program, enabling world-class science in high-energy-density physics. All run-time on the facility must be proposed to the Trident facility coordinator and all proposals go through rigorous external scientific merit review. For the first half of FY09 run on Trident, 27 proposals representing 21 unique institutions and more than 60 different users requesting 100 weeks of run-time were received. We welcome new proposals as we work to expand the user community in HEDLP.

Contact: David Montgomery, Trident director, P-24
<http://trident.lanl.gov/>



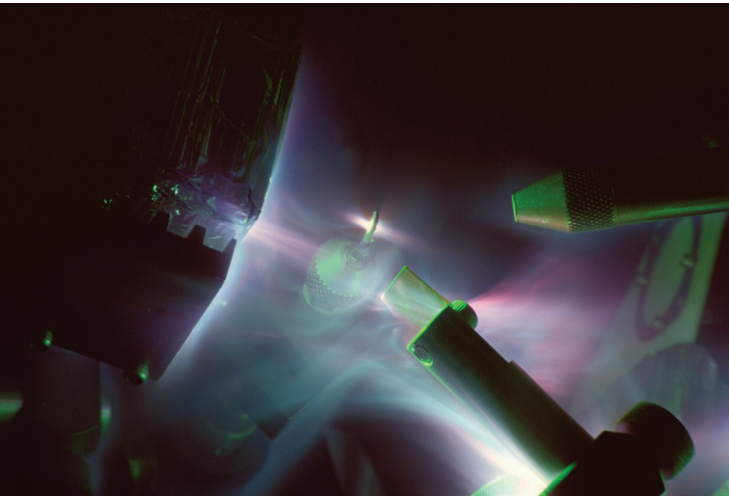
Kinetic plasma modeling of an ICF laser speckle using the LANL VPIC code shows isosurfaces of the electrostatic electric field associated with electron plasma waves that scatter laser light. [Yin et al., Phys. Rev. Lett. 99, 265004 (2007)].



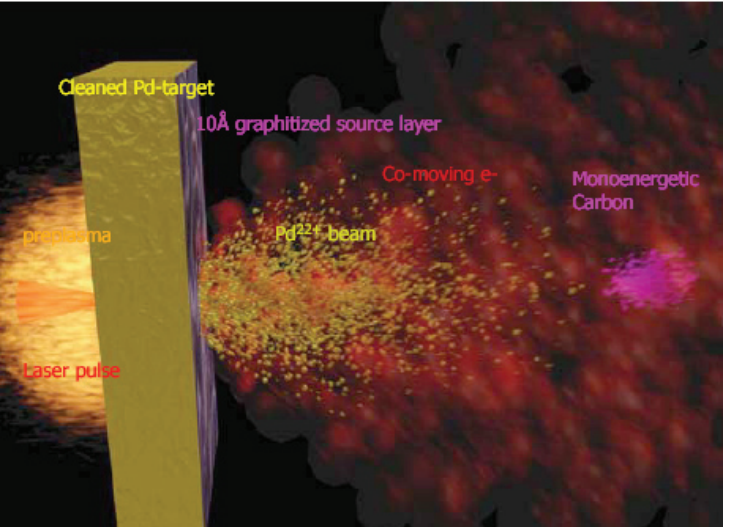
Laser-driven particle acceleration and short-pulse x-rays: The high-intensity frontier (ultra-short pulse, <100 femtosec, >100 Joule) and the next generation of compact particle and photon sources

To maintain an excellent, strong, and vital program in laser-based high-energy-density laboratory plasmas to take us into the future, Los Alamos must do research into a frontier thrust area. It is in high-power/high-intensity science which Los Alamos could excel, is exciting, and could have significant programmatic impact to national security, threat detection, and energy security. There are two programmatic areas for which high-power research is already important: high-energy incoherent x-ray generation for HEDP radiography; and charged particle beams for fast ignition or transport related studies for MeV-class particles.

The Trident 200 TW laser is capable of generating electric fields in excess of TeV/m in laser-matter interactions. 10,000 times stronger than advanced conventional accelerators, these fields can be used to accelerate ions and electrons to 10s of MeV energies in microns. Currently, Trident is the world-record holder for maximum proton and carbon ion acceleration per irradiance energy. With 80 J, Trident has been shown to accelerate ions to more than 50 MeV, nearly the same maximum energies as observed from lasers with 4-5 times the energy, namely the NOVA petawatt (500J, 58 MeV) and the RAL Vulcan PW (400J, 58 MeV) laser systems. We are at the forefront of laser-particle acceleration with several active experimental programs attempting to



Trident 200 TW laser-matter interaction on a 0.1 micron Al foil (center) and resulting plasma.



Researchers at LANL were the first to discover quasi-monoenergetic beams of mid-Z ions from laser-matter interactions, using the catalytic properties of palladium [Hegelich et. al. Nature (London) 439, p. 441 (2006)]. The ions are accelerated via the target normal sheath acceleration (TNSA) mechanism to many MeV per nucleon.

boost the energy of laser-accelerated ions toward a GeV and beyond using techniques like novel target designs (flat-top cones, and structured targets), underdense and near critical density wakefields, and new acceleration mechanisms like radiation pressure acceleration (RPA) or the break-out laser afterburner, discovered at LANL through super-massive three-dimensional PIC simulations done on the world's fastest computer, Roadrunner. In particular, Los Alamos is the world leader in ion-based fast ignition concepts, theory, and experiments.

The Trident optical parametric chirped pulse amplified (OPCPA) front-end has been recently upgraded with a second-order short pulse OPA cleaning technique, dubbed SPOPA, which has successfully cleaned the 200 TW laser to an unprecedented contrast of better than 10⁻⁹, and probably closer to 10⁻¹⁰ (so good we can't even measure it!), making Trident the world's cleanest high-power ultra-intense laser system, capable of shooting targets as thin as 5 nm. The increase to a multi-petawatt (MPW) system using OPCPA technology on Trident would allow intensities for near-visible light of greater than 10²² W/cm². Above this threshold new physics is expected: the quiver motion of the ions in the laser electric field becomes relativistic and the synchrotron radiation of the electrons in the self-magnetic field becomes important to electron dynamics. Understanding the science in this regime would enable exciting future applications such as: high-energy coherent x-ray generation based on laser-driven XFELs (described as fifth generation light sources); active interrogation using GeV-class charged particle beams; or ultra-high field plasma science and relativistic plasmas.

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Manuel Hegelich, P-24